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SOCIETAL LIFE CYCLE ASSESSMENT

Comparative life cycle assessment and social life cycle assessment of used polyethylene terephthalate (PET) bottles in Mauritius

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Abstract
Purpose Improper disposal of used polyethylene terephthalate (PET) bottles constitute an eyesore to the environmental landscape and is a threat to the flourishing tourism industry in Mauritius. It is therefore imperative to determine a suitable disposal method of used PET bottles which not only has the least environmental load but at the same time has minimum harmful impacts on peoples employed in waste disposal companies. In this respect, the present study investigated and compared the environmental and social impacts of four selected disposal alternatives of used PET bottles.
Methods Environmental impacts of the four disposal alternatives, namely: 100 % landfilling, 75 % incineration with energy recovery and 25 % landfilling, 40 % flake production (partial recycling) and 60 % landfilling and 75 % flake production and 25 % landfilling, were determined using ISO standardized life cycle assessment (ISO 14040:2006) and with the support of SimaPro 7.1 software. Social life cycle assessments were performed based on the UNEP/SETAC Guidelines for Social Life Cycle Assessment of products. Three stakeholder categories (worker, society and local community) and eight sub-category indicators (child labour, fair salary, forced labour, health and safety, social benefit/social security, discrimination, contribution to economic development and community engagement) were identified to be relevant to the study. A new method for aggregating and analysing the social inventory data is proposed and used to draw conclusions.
Results and discussion Environmental life cycle assessment results indicated that highest environmental impacts occurred when used PET bottles were disposed by 100 % landfilling while disposal by 75 % flake production and 25 % landfilling gave the least environmental load. Social life cycle assessment results indicated that least social impacts occurred with 75 % flake production and 25 % landfilling. Thus both E-LCA and S-LCA rated 75 % flake production and 25 % landfilling to be the best disposal option.
Conclusions Two dimensions of sustainability (environmental and social) when investigated using the Life Cycle Management tool, favoured scenario 4 (75 %% flake production and 25 % landfilling) which is a partial recycling disposal route. One hundred percent landfilling was found out to be the worst scenario. The next step will be to explore the third pillar of sustainability, economic, and devise a method to integrate the three dimensions with a view to determine the sustainable disposal option of used PET bottles in Mauritius.

Keywords Environmental life cycle assessment · Flake production (partial-recycling) · Incineration · Landfill · Polyethylene terephthalate (PET) bottles · Social life cycle assessment

1 Introduction

All over the world, companies make business decisions every day which affect people and environment, directly through their own operations, or indirectly through the value chain of their business (Dreyer et al. 2006). With increasing consumers' awareness on consumers' protection and rights, many companies (be it local or international) are often

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queried on the impacts the product has on people's well-being within their own facilities or at the level of their suppliers (i.e. from cradle to grave). Companies failing to respond to these growing queries in the competitive market have often been tagged with ill images. These remarks have not only tarnished the image of the companies but have also resulted in considerable losses (Hauschild et al. 2008) in the corporate or companies' turn over. Consequently, companies have recognized the urgency to conduct business in a socially responsible manner, where they undertake to care for the people affected by their business activities and at the same time be able to compete and make profit in order to survive in the marketplace.

To assist suppliers and industrialists in fulfilling these tasks, systematic analytical tools have been developed. These include life cycle assessment (LCA or Environmental LCA, E-LCA—for assessment of environmental performance) and social life cycle assessment (S-LCA—for assessment of social performance). Both dedicated tools have a wide array of applications and have been used in the present paper to determine the most environmentally efficient and socially beneficial disposal route for used polyethylene terephthalate (PET) bottles in Mauritius from four selected disposal alternatives.

Mauritius is a democratic and a prosperous small island developing state, found in the Indian Ocean, some 2,000 km off the south eastern coast of Africa. The island is only 1,865 km^2 in size and has an estimated population of 1.3 million (Central Intelligence Agency 2012). The island is famously recognized as a worldwide high tourist destination. Over the years, with population growth and changing consumption patterns, the amount of solid waste generated has progressively increased from 0.6 kg per person per day in the late 1990s to nearly 1 kg per capita per day in 2010 or 345 kg of waste per capita per year (Foolmaun et al. 2011). Likewise, over the years, there has been a sharp increase in the demand for drinks bottled in polyethylene terephthalate (PET) containers (Foolmaun and Ramjeeawon 2012). In 2010, nearly 105 million PET bottles were used by the three main beverage companies of Mauritius to bottle soft drinks and plain water. The normal disposal route of the used PET bottles is through landfilling. As there is no formal waste segregation, used PET bottles are disposed of co-mingled with domestic waste at the sole sanitary landfill. However, improper disposal of used PET bottles by consumers constitute an eyesore to the environmental landscape. Moreover, stagnated water in used PET bottles serves as ideal breeding places for mosquitoes. The latter are vectors/propagators of diseases such as Malaria, yellow fever, dengue fever and chikungunya. Altogether, these environmental impacts are viewed as a serious impediment to the flourishing tourism industry in the Small Island Developing State of Mauritius (Foolmaun and Ramjeeawon 2008).

Lately with the setting up of a flake producing industry,[1] a slight improvement has been noted in the amount of used PET bottles disposed indiscriminately. Nonetheless, a significant number of used PET bottles still find their way onto watercourses, drains, barelands and abandoned sites, indicating that the disposal of used PET bottles remains a major concern in Mauritius (Foolmaun and Ramjeeawon 2012).

Of prime importance is therefore to determine a suitable disposal method of used PET bottles which not only has the least environmental load but at the same time has minimum harmful impacts on peoples employed in waste disposal companies. LCA is the perfect tool to determine the best disposal option from an environmental perspective. However, decision based from an environmental perspective is not necessarily the best option when analysed from a social perspective. Similarly, a disposal option with least social impacts may yield the highest pollution load when investigated by life cycle assessment or other environmental assessment tools (Foolmaun and Ramjeeawon 2012). Moreover, Reitinger et al. (2011) argued that LCA does not cover some important impacts on human lives; however, these can be captured by performing an S-LCA. Thus studies undertaken separately (that is either from an environmental or social perspective) may lead to different conclusions and decisions. It follows, therefore, that investigating both environmental and social domains of sustainability will direct to a better understanding of the product system as well as the social impacts and the performance of the companies involved. The ultimate aim of the two assessment tools (LCA and S-LCA) is to safeguard the Areas of Protection through rational decision making. It is in this respect that both tools, with life cycle perspectives: LCA and S-LCA were selected for the present study to investigate and compare the environmental and social impacts of four selected disposal alternatives of used PET bottles (two existing scenarios—scenarios 1 and 3) and two new scenarios (scenarios 2 and 4—these scenarios do not exist presently but are envisaged to be the potential disposal routes in the near future). The four disposal routes investigated were:

- Scenario 1: 100 % landfilling (all used PET bottles are sent to the landfill)
- Scenario 2: 75 % incineration with energy recovery and 25 % landfilling (75 % of used PET bottles are sent to

[1] This private industry collects used PET bottles from special bins placed in strategic points throughout the island like hypermarkets, fairs etc. The industry also purchases used PET bottles from individuals, NGOs, private organizations. Thus there is an informal separate collection of used PET bottles and the collection rate in 2010 was 40 %. At the industry, used PET bottles are baled, shredded into flakes and bagged for export to South Africa. Since only part of the recycling process takes place in Mauritius, flake production can be referred to as partial recycling.

the incinerator for energy recovery and the remaining 25 % are landfilled)

- Scenario 3: 40 % flake production and 60 % landfilling (the actual scenario—40 % of used PET bottles are diverted to the flake production industry, while the rest goes to the landfill)
- Scenario 4: 75 % flake production and 25 % landfilling (similar to scenario 3, the collection rate and hence flake production rate has been increased to 75 % and the remaining 25 % goes to the landfill)

The objectives of study were to:

- Determine the disposal option with the least environmental impact
- Find out the disposal option which causes the least social impacts
- Communicate the results to the bottling industries
- Assist Government of Mauritius to formulate appropriate policy decision regarding disposal of used PET bottles

2 Methodology

Environmental impacts of the four scenarios were evaluated using the life cycle assessment (E-LCA) methodology as prescribed by ISO 14040:2006, whilst the social impacts were determined using the UNEP/SETAC Guidelines on Social Life Cycle Assessment (S-LCA).

3 Life cycle assessment

Life cycle assessment is a tool to assess the potential environmental impacts and resources used throughout a product's lifecycle, i.e. from raw material acquisition, via production and use phases, to waste management (ISO 2006a). LCA allows a comprehensive view of the various impacts on the environment, enabling the identification of suitable measures from a sustainable development prospective (Chehebe 1997; Jensen 1997; Graedel, 1998 as cited by Ruviaro et al. 2011). One of the main strengths of LCA is the comprehensiveness of the approach and the resulting avoidance of problem shifting between impacts or areas (Finnveden et al. 2009). A comprehensive systematization of the requirements and steps of the LCA is contained in the standards ISO 14040:2006 (ISO 2006a) and ISO 14044:2006 (ISO 2006b).

ISO, however, never aimed to standardize LCA methods in detail (Guinée et al. 2011). Consequently, there is no common agreement on how to interpret some of the ISO requirements. As a result diverging approaches that may have a tense relation with some of the basic principles of the ISO standards have been developed (Guinée et al. 2011) with respect to system boundaries and allocation methods (Finnveden et al. 2009; Zamagni et al. 2008, as quoted by Guinée et al. 2011), dynamic LCA (Pehnt 2006; Levasseur et al. 2010), spatially differentiated LCA (Finnveden et al. 2009; Zamagni et al. 2008, as quoted by Guinée et al. 2011), risk-based LCA (Nishioka et al. 2006) and environmental input–output based LCA(EIO-LCA) based and hybrid LCA (Suh et al. 2004; Heijungs et al. 2006). The diverging approaches coupled with increasing maturity and methodological robustness of LCA (Finnveden et al. 2009) has enabled a widespread of application of LCA, including product development in industry, marketing of products, ecolabellings, and decision making, just to name a few. Moreover, LCA is the cornerstone of various European policies making such as the Integrated Product Policy, the Waste Prevention and Recycling and the Sustainable Use of Natural Resources (Finnveden et al. 2009).

The ISO standards 14040:2006, define four basic steps in E-LCA namely:

- Goal and scope definition
- Inventory analysis
- Impact assessment
- Interpretation

These steps are well described and commented in (Rebitzer et al. 2004; Pennington et al. 2004). In addition, these authors have provided a review of the recent developments in LCA methodology which later have been further build on by Finnveden et al. (2009) and Guinée et al. (2011). Moreover, a concise literature review on various disposal methods of used PET bottles is provided in Foolmaun and Ramjeeawon (2008, 2012) and these authors have found out that recycling is the most preferred option for disposal of used PET bottles. Moreover, these authors have also detailed the methodology for evaluating the environmental impacts of the four disposal scenarios. The detailed LCA methodology will therefore not be discussed here, instead a few important features for each phase will be defined and results will be presented.

3.1 Goal and scope definition

3.1.1 Functional unit

The functional unit was defined as the disposal of 1 tonne of used PET bottles to the respective disposal facilities.

3.1.2 System boundary

The system boundary was defined from the point the consumers disposed their used PET bottles up to the moment they lost totally their value i.e. either through landfilling,

flaking or incinerating the used PET bottles, as shown in Fig. 1. For scenarios 3 and 4 (which are also partial raw material production scenarios), the boundary was set at the point the flakes left the Mauritian territory—thus as shipment and various processes leading to recycling, happened outside the system boundary and were therefore not considered in the study. Furthermore, upstream processes related to the manufacture and uses of the PET bottles were excluded from the system boundary.

3.2 Inventory analysis

The most time-consuming step is the inventory analysis, in particular, data collection. Data were collected from various sources including technical reports, publications, personal communications from staff of Ministry of Local Government; Ministry of Environment and Sustainable Development and from eco-invent database of Sima Pro 7.1. Data were processed with the support of Sima Pro 7.1 software. The emissions released by the different scenarios are shown in Table 1.

3.3 Impact assessment

The purpose of the life cycle impact assessment (LCIA) is to provide additional information to help assess the results from the Inventory Analysis so as to better understand their environmental significance (ISO 2006a). Thus, the LCIA should interpret the inventory results into their potential impacts on what is referred to as the 'areas of protection' of the LCIA (Finnveden et al. 2009).

The impact assessment method selected for the present study was Eco-indicator 99 and was used to investigate the following impact categories in the model: carcinogens, respiratory organics, respiratory inorganics, climate change, radiation, ecotoxicity, ozone layer, acidification/eutrophication, land use, mineral and fossil fuel. The comparison results based on characterization and single score are illustrated in Figs. 2 and 3, respectively.

Characterization results of Fig. 2 indicated that scenario 1 (100 % landfilling) impacted negatively on almost all impact categories, whilst the other three scenarios showed both

Fig. 1 System boundary

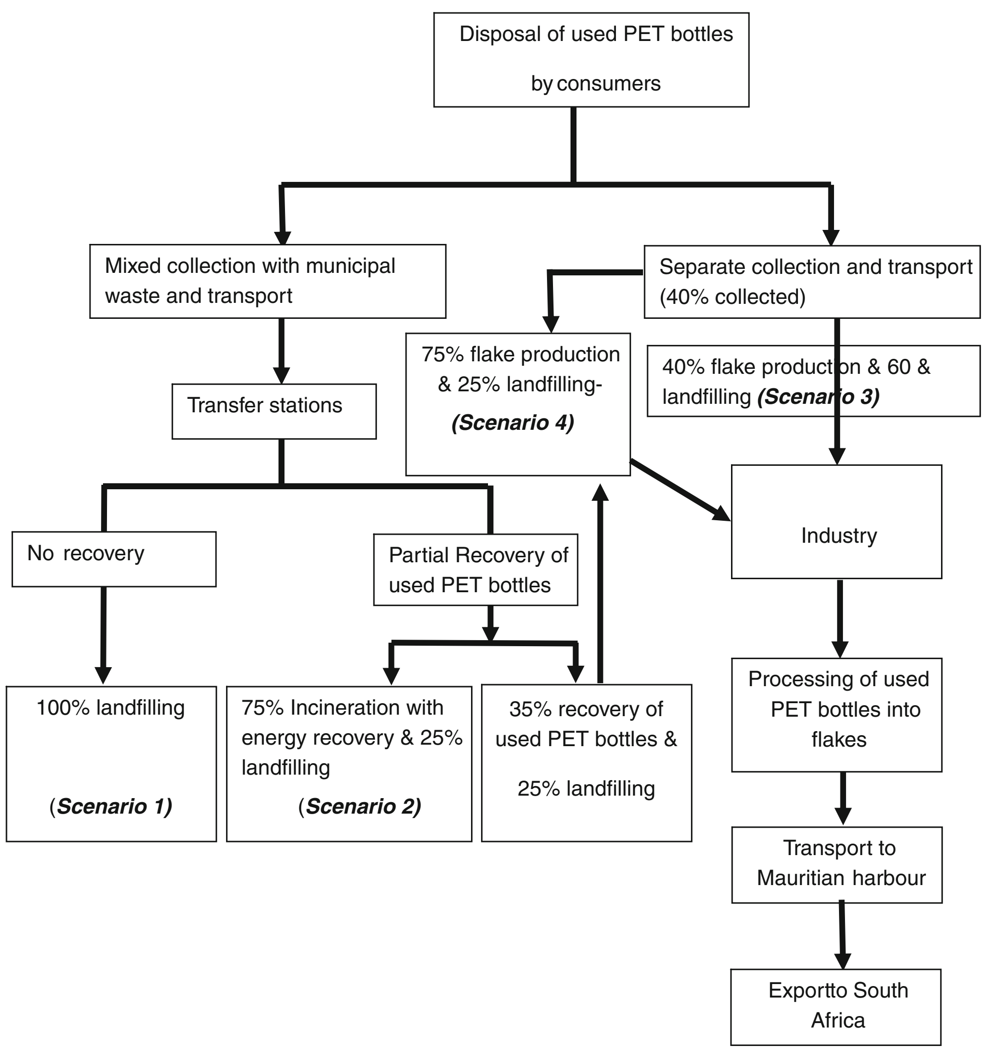

Table 1 Summary of emissions for the four scenarios

Substances	Unit	Scenario 1–landfill (100 %)	Scenario 2–75 % incineration with energy recovery and 25 % landfilling	Scenario 3–40 % flake production and 60 % landfilling	Scenario 4–75 % flake production and 25 % landfilling
Air emissions					
PM_{10}	kg	0.0033	0.0169	0.0618	0.113
SO_2	kg	0.0168	0.0675	0.872	1.62
NO_2	kg	0.0994	−1.77	−5.66	−10.7
CO_2	kg	25.2	1965.6	648	1.19E3
CH_4	kg	2.11	0.61	1.68	1.31
Cd	kg	3.82E-7	−7.49E-5	1.81E-5	3.35E-5
Pb	kg	3.91E-6	−0.009	0.0002	0.0003
Dioxins		5.26E-12	2.61E-8	9.91E-11	1.81E-10
As		7.69E-7	2.7E-6	4.11E-5	7.63E-5
Water emissions					
BOD	kg	35.753	9.103	24.276	14.223
Chloride ions	kg	0.967	−9.577	7.726	13.640
COD	kg	151.113	37.935	94.655	45.254
Nitrate	kg	0.547	0.126	0.335	0.150
Sulphate	kg	0.453	1.207	−0.241	1.867
Suspended substances	kg	0.002	0.012	0.176	0.329
TOC	kg	138.239	34.594	85.870	40.047

positive and negative contributions to the impact categories. These results when translated to single score results, Fig. 3, indicated that three scenarios (scenarios 2, 3 and 4) occurred below the impact threshold level of the three areas of protection (human health, ecosystem quality and resources). Scenario 1, on the other hand, impacted negatively on the defined areas of protection, implying thereby that it was the worst disposal option.

3.4 Interpretation and discussion

Negative values in the three scenarios are synonymous to net environmental benefits and are attributed to avoided emissions. In scenario 2, energy recovered from incineration was used to generate electricity for the plant as well as for the national grid. Had electricity not been produced by incineration, an alternative source of fuel, oil (which is more polluting), would have been required to produce the equivalent electricity. However, as oil as fuel was not used, its emissions were thus avoided.

Scenarios 3 and 4, being partial recycling scenarios, also gave net environmental benefits. Through recycling, used PET bottles were intercepted from municipal solid waste which otherwise would have been landfilled and would have impacted negatively onto the environment as in scenario 1.

In general, the higher the negative values, the more was the avoided emissions and therefore the better was the net environmental benefit. It is therefore established from Fig. 3, that scenario 2 was better than scenario 3, while scenario 4 provided the highest environmental benefits and was, therefore, the most environmental friendly disposal option for used PET bottles in Mauritius. This finding is in line with the conclusion of a recent major research report published in March 2010 by the Waste & Resources Action Programme (WRAP; Michaud et al. 2010) on Environmental Benefits of Recycling. This research reviewed some 200 life cycle analyses of key materials in UK waste streams and evaluated the impact on the environment of recycling, landfilling or incineration. They found out that recycling was the most favourable disposal route among the various disposal scenarios studied.

4 Social life cycle assessment (S-LCA)

S-LCA is a very young research discipline where many works are in progress. One recent development was the publication of the UNEP/SETAC 'Guidelines for Social Life Cycle Assessment of Products' (Reitinger et al. 2011). The guidelines demystify the assessment of product life cycle

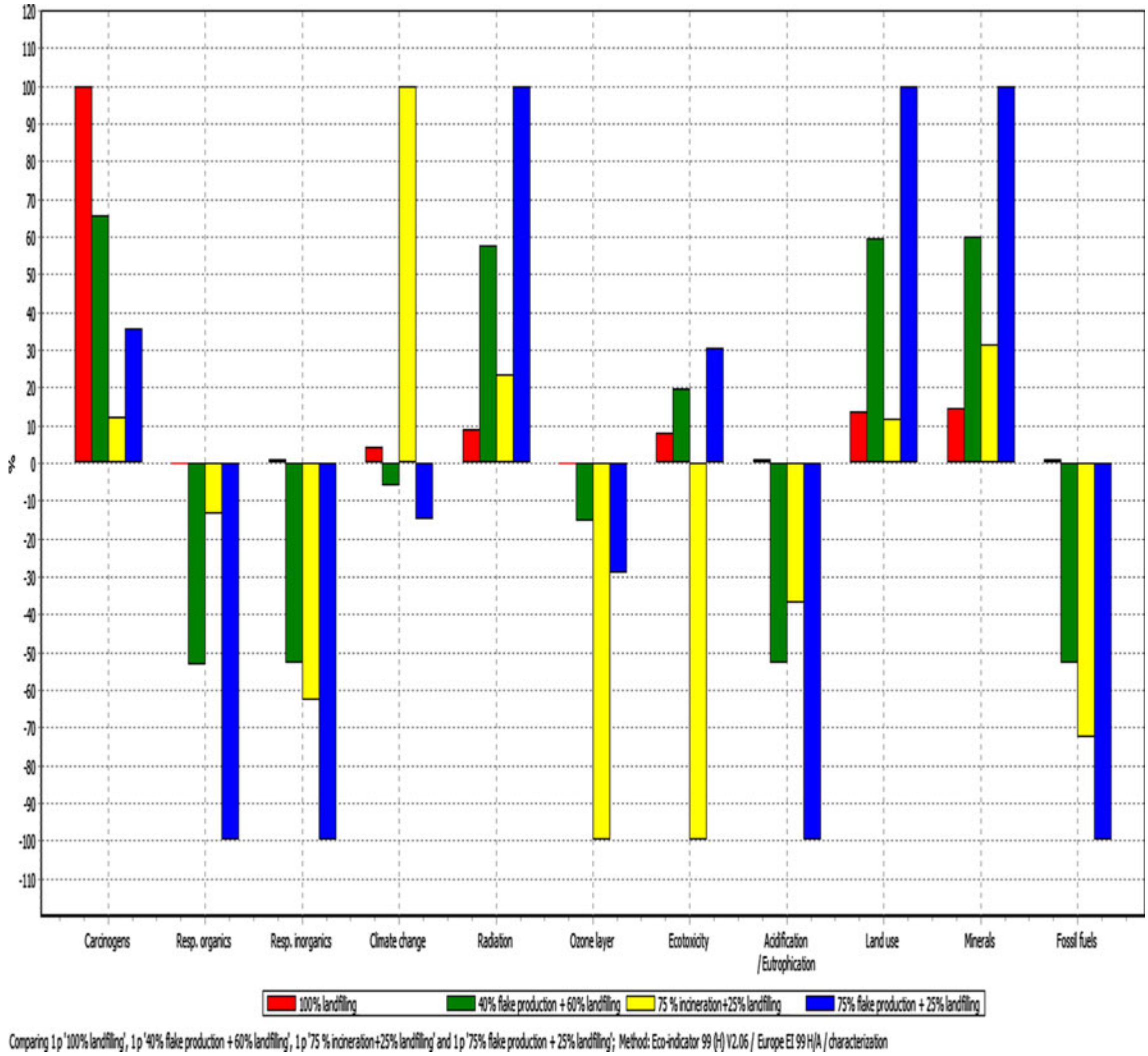

Fig. 2 Characterization results

social impacts and present an effective framework representing the consensus of an international group of experts leading research in this field (Benoît et al. 2010).

4.1 UNEP/SETAC frameworks of S-LCA

A framework for Social LCA, which has been adapted from the ISO standardized Environmental LCA Framework (Benoît et al. 2010), has been proposed in the guidelines on SLCA and has been applied in the present study.

The UNEP/SETAC Guidelines on SLCA recommend that the framework for E-LCA be retained for determining S-LCA. The methodology therefore comprises of the following four phases:

- ○ Goal and scope definition
- ○ Inventory analysis
- ○ Impact assessment
- ○ Interpretation

These phases have been well elaborated in (UNEP 2009; Jørgensen et al. 2008; Ciroth and Franze 2011) and will therefore not be described here. Only important features will be highlighted.

4.2 Goal and Scope definition

The first step in the S-LCA process is to define a clear goal which then shapes how the study is undertaken. There is, however, a marked division among S-LCA researchers in their approach to scope definition. Some S-LCA researchers favoured a method similar to E-LCA which focused on the process of the product development (Schmidt et al. 2004), while others (Spillemaeckers et al. 2004 as quoted by Jørgensen et al. 2008; Dreyer et al. 2006, UNEP 2009; Macombe et al. 2011; Zamagni et al. 2011) questioned the process based approach and suggested that the conduct of the companies should be the main component of the S-LCA

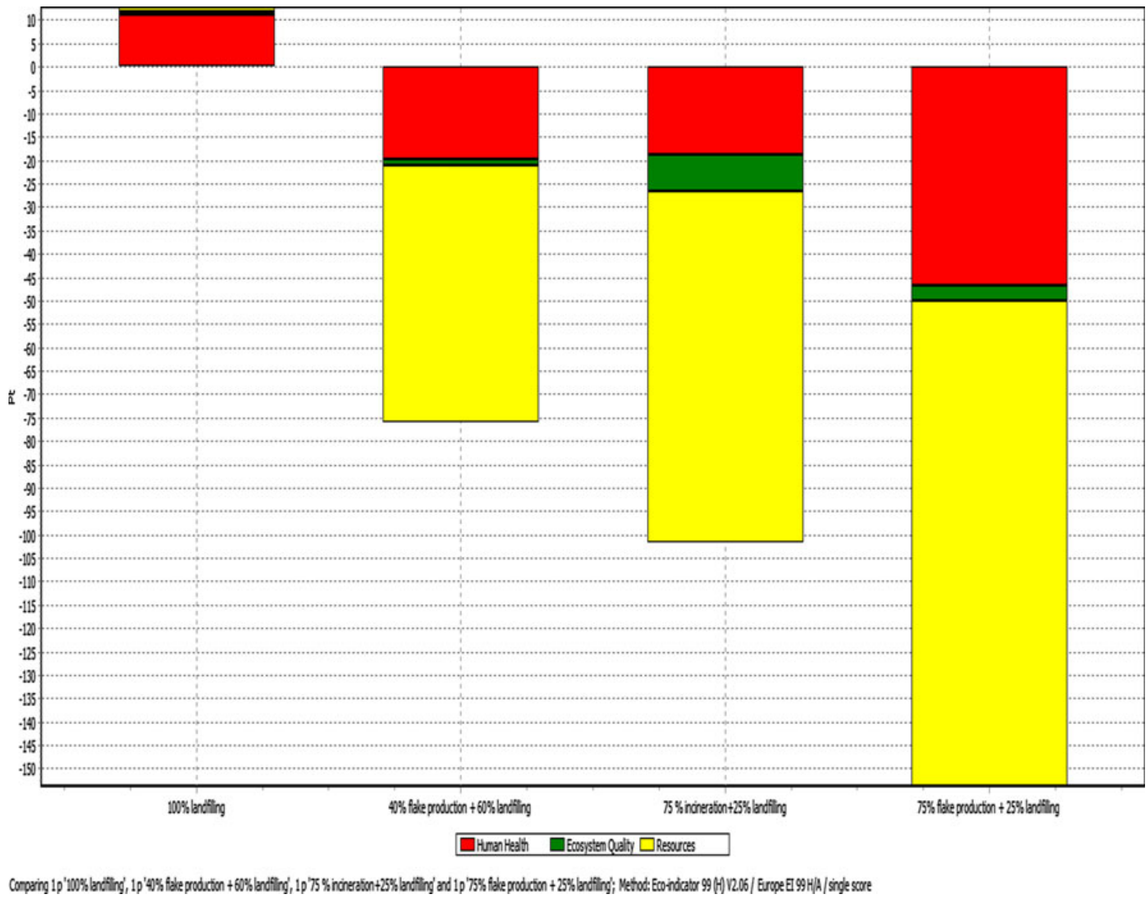

Fig. 3 Single score results of the four scenarios

analysis. Dreyer et al. 2006 however, cautioned that with this approach, problem may arise if the company produces more than one product- in such situation, it may become difficult to decide the basis or share of total social impacts to be attributed to the respective products. Nevertheless, the share of the total social impacts or the allocation factor could be based for instance on value creation or the number of labour hours spent, (Dreyer et al. 2006). Despite the two different approaches, it is believed that both approaches (process and company conduct approaches) are necessary and add complementary information (Paragahawewa et al. 2009). Likewise, even for system boundaries (also termed as perimeter by Macombe et al. 2011), two different approaches have been adopted by S-LCA practitioners. The first approach is to narrow the system boundary to those parts of the life cycle which is directly influenced by the company performing the assessment. This approach was used by (Méthot 2005; Dreyer et al. 2006, 2010) where only the company and its closest suppliers and distributors were assessed. Such an approach has similarities with Corporate Social Responsibility (CSR) where the concern is with the conduct of a specific company and its social impact rather than the social impacts of a product across its whole life cycle (Paragahawewa et al. 2009). The second approach (adopted by Spillemaekers et al. 2004 as quoted by Jørgensen et al. 2008; Barthel et al. 2005; Weidema 2005) is to include the entire life cycle, but to exclude processes that do not significantly change the overall conclusions of the study. Still another approach relates to the work of Aulisio, as presented in a second international seminar[2] on S-LCA and reported by Macombe et al. 2011. This author suggested that the organizations under scrutiny are exactly those whose unit processes would be involved if an environmental LCA was performed (Macombe et al. 2011).

4.2.1 Goal and scope definition of the present study

The goals of S-LCA were similar to the corresponding E-LCA, i.e.:

- To carry out the social life cycle assessment of four disposal scenarios of used PET bottles; and
- To determine the disposal option which is socially more attractive/beneficial

[2] The second international seminar in social life cycle assessment held on 5-6 May 2010 in Monpellier, France.

The four disposal scenarios, the functional unit, the system boundaries were similar to those defined in the corresponding LCA study so as to maintain consistency for both studies. Maintaining consistency has the added advantages that the results of both studies are reported under similar conditions/context which also implies that the results can be made easily comparable (for instance can be converted to common comparable units), and at the same time can be integrated into the life cycle sustainability assessment, where one of the pre-requisite conditions is to have consistent (ideally identical) system boundaries of the three tools (Kloepffer 2008) assessing the three domains of sustainability.

4.2.2 Selection of stakeholder categories and sub-categories indicator

The choice of impact categories, sub-categories and characterization models shall be made in accordance with the goal and scope of the study (UNEP 2009). According to the UNEP/SETAC Guidelines on S-LCA, there are five main stakeholder categories within an S-LCA: workers/employees, local community, society, consumer and value chain actors. Within those, there are many subjective impact categories such as child labour, fair salary, equal opportunity, migration, secure living conditions and technology development. The list is not exhaustive as research is underway to broaden the categories. For instance, future generation has been identified as an important stakeholder category where further reflections and assessment will be needed (UNEP 2009).

With respect to the defined system boundary, only three stakeholders (workers, society and local community) and eight sub-categories were found of relevance for the four disposal scenarios. These are presented in Table 2. To be able to assess the status of the different sub-categories, several indicators were also selected.

4.2.3 Main assumptions

The following main assumptions were made:

- All stakeholders sub-categories have equal weightage, although sub-categories and stakeholders are not equal in their relevance.
- As incineration plant does not exist presently in Mauritius, social information was obtained from the Environment Impact Assessment report of a proposed incineration plant in Mauritius. It is assumed that the social benefits mentioned therein are implemented.

4.3 Inventory analysis

The objective of the inventory analysis is to collect and analyse relevant information (inventory indicators), identified during the scope definition (Paragahawewa et al. 2009). An important step in inventory analysis is data collection. There is some disagreement among researchers on the type of information to be collected for S-LCA (Paragahawewa et al. 2009). Some researchers argued that method similar to E-LCA was not applicable to S-LCA (e.g. Dreyer et al. 2006; Spillemaeckers et al. 2004 as quoted by Jørgensen et al. 2008). Other authors (Weidema 2006; Schmidt et al. 2004; Barthel et al. 2005) claimed that generic data from statistical databases could give a rough estimate on several social impacts. They therefore favour collection of site specific data in S-LCA.

Table 2 Stakeholder categories and sub-categories indicators

Stakeholder categories	Sub-category indicators	Indicator
Workers	Child labour	Percentage of child labour in organisation
	Fair salary	Satisfaction in wages paid by organization
	Forced labour	Whether workers are forced to work
	Health and Safety	• Awareness on health and safety issues;
		• Awareness of steps/protocol to follow in case of emergency/accidents
		• Percentage of accident/injury in the organization
		• Use of protective equipment
	Social benefit/social security	Lists of social benefits provided to workers
	Discrimination	Existence of sex discrimination during recruitment of workers
Society	Contribution to Economic Development	Number of jobs created
Local community	Community engagement	Percentage of Corporate Social Responsibility fund spent on community projects

Swarr (2009) added that even if site generic data were used, SLCA would have to allow for location-specific valuation to account for the different priorities of different communities. Site-specific models would likely be too complex for product designers, but it may be possible to use national and regional models as calibration standards for simpler design support tools (Reap et al. 2008). Moreover, the additional steps of data collection and modelling necessary to link midpoint attributes to specific damages, can introduce large uncertainties (Swarr 2009). Further, due to the uncertainty of the causal relationships, damage modelling may cloud the understanding of the causal links between the conduct of the company and the damage upon the area of protection (Dreyer et al. 2010). Finally, Ciroth and Franze (2011) agreed that for a reliable S-LCA study, country-, sector- as well as organisation-, and site-specific data are needed. Organisation- and site-specific data are essential for the investigation of specific companies, but also country- and sector-specific information is important.

4.3.1 Data collection for the study

It was vital to gather the opinions and attitudes of the main stakeholders involved in the four defined scenarios. Since these data were not readily available, it was judged necessary to obtain these data through a survey questionnaire. A survey is very useful in eliciting a wide range of information from the study population in short period of time. The questionnaire covered the three stakeholders categories and the eight sub-categories indicators.

It was deliberately prepared in a simple language and involved ‘yes’ or ‘no’ type questions as it was to be administered to workers with very low academic background. Convenience sampling, which is a non-probability type of sampling, was used for the study. Convenience sampling has the advantage that it is fast, inexpensive, easy and involves use of ‘the most conveniently available people as study participants’. This method also facilitates access to the maximum amount of data while ensuring efficiency in terms of time and financial resources.

The questionnaire was designed for the waste management sector, more specifically to be administered to:

- The scavengers (private and state)
- Landfill workers
- Incinerator workers
- Flake producing industrial workers

The population of these workers was estimated to be 4,650, out of which 4,500 were scavengers involved in collection of domestic wastes throughout the island. The representative sampling size was found out to be 140 using the Raosoft sample size calculator. Consequently, 140 questionnaires were administered to the various group workers.

Table 3 The proposed scoring system

Sub-category indicators	Percentage	Marks
Child labour	0–20	4
	21–40	3
	41–60	2
	61–80	1
	81–100	0
Fair salary	0–20	0
	21–40	1
	41–60	2
	61–80	3
	81–100	4
Forced labour	0–20	4
	21–40	3
	41–60	2
	61–80	1
	81–100	0
Social benefit/social security	0–20	0
	21–40	1
	41–60	2
	61–80	3
	81–100	4
Discrimination	0–20	4
	21–40	3
	41–60	2
	61–80	1
	81–100	0
Community engagement	0–20	0
	21–40	1
	41–60	2
	61–80	3
	81–100	4

The questionnaires were filled on-site during face to face interviews with the workers. Interviews with the respective management were also scheduled, to cross-check the veracity of the information provided by workers while ensuring confidentiality of the information of both parties. The interviews with management were facilitated with the preparation of another questionnaire which was basically similar to

Table 4 Scoring system for number of jobs created

Number of jobs created	Scores
1–225	1
226–450	2
451–675	3
676–900	4

Table 5 Summary of results of seven sub-categories for the three disposal facilities

Stakeholder	Sub-category indicators	Calculated percentage for		
Workers		Flake producing industry	Landfilling	Incineration
	Child labour	0	0	0
	Fair salary	80	36.25	70
	Forced labour	0	21.45	0
	Social benefit/social security	100	100	100
	Discrimination	0	0	0
Society	Contribution to Economic Development (Job creation	55 direct workers+ 800 indirect	91 (50 workers at landfill+41 scavengers for collection)	131 (60 workers at incineration plant+ 71scavengers for collection)
Local community	Community engagement	0	10	19

the questionnaire of the workers but set in a different way and requiring some additional information.

4.4 Life cycle impact assessment (LCIA)

This phase traces the inventory data and defines the social and socio-economic impact (UNEP 2009). It basically involves:

- Linkage of inventory data to particular S-LCIA sub-categories and impact categories (classification)
- Determination and/or calculation of sub-category indicator results (characterization)

As in E-LCA, the classification is implicitly part of the characterization models (social and socio-economic mechanisms) development (UNEP 2009). However, in S-LCA, it is still being debated whether to follow the E-LCA approach or to classify according to the impacted stakeholders (Grießhammer et al. 2006). In addition, Dreyer et al. (2010) stated that many social impacts are difficult to capture in a meaningful way using traditional quantitative single criterion indicators. These authors therefore argued that the results of social LCIA must be meaningful to the company, it must be easy to trace them back to tangible managerial measures, and they must be sufficiently sensitive to reflect changes in the management practice.

4.4.1 Impact assessment method

To-date, there is no scientific based classification models of social life cycle inventory parameters nor there are any internationally accepted impact assessment methods available (Ciroth and Franze 2011). These authors have proposed a new method to aggregate the inventory data. In contrast to E-LCA, their S-LCIA methodology assesses impacts as well as the performance of the considered sector/companies. The performance of the companies/sectors is assessed with respect to performance reference points such as ILO conventions, the ISO 2600 guidelines, and the OECD Guidelines for Multinational Enterprises, while the impacts of the company/sector behaviour is assessed with regard to the selected impact categories. Their assessment also uses the UNEP listed impact categories/stakeholders sub-categories and is conducted based on a colour scale with six shades. The meaning of the colours is intuitive: Green nuances mean good performance/positive impact; yellow nuances mean rather poor performance/negative impact; red means very poor performance/very negative impact. Orange and red assessments show social hot spots. A specific factor is

Table 6 Results of health and safety sub-category for the three disposal facilities

Indicator	Calculated percentage for		
	Flake producing industry	Landfilling	Incineration
Awareness on health and safety issues	92	58.75	90
Awareness of steps/protocol to follow in case of emergency/accidents	100	75	100
Percentage of accident/injury in the organization	10	7.5	0
Use of protective equipment	100	100	100

Table 7 Score of health and safety sub-category for the three disposal facilities

Indicator	Scores		
	Flake producing industry	Landfilling	Incineration
Awareness on health and safety issues	4	3	4
Awareness of steps/protocol to follow in case of emergency/accidents	4	3	4
Percentage of accident/injury in the organization	4	4	4
Use of protective equipment	4	4	4
Total scores	16	14	16
Average	4	3.5	4

assigned to every colour to allow quantification of the impacts. The factors of all sub-categories are summed up for every process and the resulting amounts for the company/sector performance and that of the impacts are divided by the number of sub-categories (Ciroth and Franze 2011).

4.4.2 Proposed impact assessment method for the study

A new methodology for aggregating the inventory results, which is in line with the UNEP/SETAC Guidelines on S-LCA, is being proposed. This methodology is based on a scoring system and assesses the performance of a company with respect to selected sub-categories. This methodology aims at converting qualitative inventory information into quantitative social and socio-economic inventory data and aggregating them using a scoring system. The idea behind assigning scores to indicators and sub-categories is thus to aggregate the inventory results and convert them into figures that could be eventually summed up and compared with alternative scenarios.

The proposed model has three basic steps:

- Conversion of inventory results (indicators) into percentage

Data collected with respect to predefined indicators are expressed in percentage[3]

- Assigning scores to indicators and sub-categories

A score is assigned to each sub-category by classifying the percentages obtained in the previous step in one of the five categories of percentages[4] namely: 0–20 %, 21–40 %, 41–60 %, 61–80 % and 81–100 %. The score allocated to each sub-category ranges from 0 to 4 as shown in Table 3.

For sub-categories having more than one indicator, as in the case of sub-category ‘Health and Safety’ in Table 2, similar markings ranging from 0 to 4 is used for each indicator. The total marks allocated in this case to that particular sub-category will be the average marks of number of indicators the sub-category had. For the sub-category, ‘contribution to economic development’ a somewhat different approach should be used. In this particular case, the number of jobs created was categorized into 4 groups[5] so as to be consistent with the 1 to 4 scoring system as indicated in Table 4.

- Summation of the scores

  The score obtained for each sub-category under a defined scenario are summed up to obtain a ‘single score’, thus allowing comparison with other like scenarios. In the cases of combined scenarios for example, 40 % flake production and 60 % landfilling, the three steps are similar. A slight modification is, however, needed in step 3—prior to the obtaining of the single score. To obtain the scores for a combined scenario, the total score for each single scenario is first multiplied by the percentage it represents in the combined scenario and the resulted figures are added to yield the final single score. As example for 40 %flake production and 60 % landfilling, the score calculated is as follows:

$$[(\mathrm{Totalscoreforflakeproducingindustry}) \times 40/100] + [(\mathrm{Totalscoreforlandfilling}) \times 60/100]$$

Obviously, there are two important assumptions to be made in this model. First, all indicators and sub-categories carry equal weightage (i.e. the weighting factor is one) and therefore allow normal summation, otherwise weighting factors need to be calculated prior to summation. Second assumption concerns the single score of combined scenario.

[3] An example would be: the number of workers answering yes to the question on wage satisfaction in the survey—this would represent the fraction of the sampled population of workers satisfied with their wages. This fraction can then be converted into percentage.

[4] For instance, if 55 % of workers were satisfied with their salary then the score allocated would be 2, according to Table 3.

[5] As example, if an organization creates 500 jobs, then the score allocated as per Table 4 would be 3.

Table 8 Scores for the three disposal facilities

Stakeholder	Sub-category indicators	Scores		
		Flake producing industry	Landfilling	Incineration
Workers	Child labour	4	4	4
	Fair salary	3	1	3
	Forced labour	4	3	4
	Health and safety	4	3.5	4
	Social benefit/social security	4	4	4
	Discrimination	4	4	4
Society	Contribution to economic development (job creation)	4	1	1
Local community	Community engagement	0	0	0
Total scores		27	20.5	24

In practice, the social impacts or the single score obtained in each single scenario is not necessarily linearly related to the level of production. However, in this model to obtain the single score of the combined scenario, it is assumed that single score of single scenarios is linearly related to the production level. This is, indeed, an area where further research is warranted.

The new model proposed is used in the present study to evaluate the impacts of the performance of organizations, involved in waste management sector in Mauritius, on the well-being of the workers, society and the local community using eight selected indicators listed in Table 2. Data on each indicator was collected through the questionnaire surveys (please refer to Section 4.3.1). The single score of each combined scenario was calculated according to the steps already detailed above.

4.5 Interpretation

The results will be presented and discussed in the later sections.

5 Results

5.1 Inventory results

The results of the questionnaires administered to the various group of workers are summarized in Table 5, which shows the results of all stakeholders categories, except that of health and safety, for the three disposal facilities namely flake producing industry, landfill and incineration plant. The results of the sub-category health and safety are presented in Table 6.

5.2 Impact assessment

Tables 7 and 8 show the aggregated inventory results under the proposed scoring system. Table 7 shows the scores obtained for the health and safety sub-category while Table 8 shows the total scores for the 8 sub-categories.

The total score for each scenario was worked out according to the equation provided under Section 4.4.2. The final scores are given in Table 9.

5.3 Interpretation

The inventory results confirmed that there were no cases of child labour, sex discrimination, forced labour (at flake producing industry and incineration plant), and all workers enjoyed social benefits. Thus these sub-categories scored highest points in Table 8. The landfilling system recorded 21.45 % of forced labour; 63.75 % and 30 % of workers of the two disposal facilities, landfill and incineration, respectively, were not satisfied with their present salaries, while 80 % of workers employed at flake producing industry claimed to be satisfied. It should however be pointed out

Table 9 Final scores for the disposal scenarios

Disposal scenario	Score	Hierarchy
Scenario 1: 100 % landfilling	20.5	4
Scenario 2: 40 % flake production & 60 % landfilling	23.10	3
Scenario 3:75 % incineration & 25 % landfilling	23.13	2
Scenario 4: 75 % flake production & 25 % landfilling	25.37	1

Table 10 Colour rating system proposed by Ciroth and Franze (2011)

Performance assessment	Impact assessment	Colour	Factor
Very good performance	Positive effect		1
Good performance	Lightly positive effect		2
Satisfactory performance	Indifferent effect		3
Inadequate performance	Lightly negative effect		4
Poor performance	Negative effect		5
Very poor performance	Very negative effect		6

that salaries are not fixed by individual organization, instead are decided by the Pay Research Bureau (PRB) for state workers and by the National Remuneration Board (NRB) for private workers upon consultation with the employer, employee (through trade union) and government. Interview with employers of the respective organizations opined that they pay their workers according to the rate determined by PRB or NRB. However, this could not be confirmed as the salaries paid to the workers were kept confidential.

The results also indicated that all workers were provided with protective equipment by their respective organizations. Workers employed at flake producing industry and incineration plant were fully aware of the procedures to follow in case of emergency/accidents while only 50 % of the workers involved in the landfill system were aware of such procedures. Moreover, 51.25 % of workers employed in the landfill system were never briefed on health and safety issues, while

Table 11 Results of LCIA method by Ciroth and Franze (2011), for flake producing industry

Stakeholder	Subcategory	PA	%CL	SW	FL	HS	SB	D	IA
Worker	Child labour	1	√	√	√	√	√	√	1
	Fair salary	2	√	√	√	√	√	√	1
	Forced labour	1	√	√	√	√	√	√	1
	Health and Safety	2	√	√	√	√	√	√	1
	Social benefit/social security	1	√	√	√	√	√	√	1
	Discrimination	1	√	√	√	√	√	√	1
	Amount	1.34							1
society	Contribution to Economic Development	1	√	√	√	√	√	√	1
	Amount	1							1
local community	Community engagement	6	√	√	√	√	√	√	6
	Amount	5							5
Total amount		**2.45**							**2.34**

% CL=Percentage of child labour in organisation

SW=Satisfaction in wages paid by organization

FL=whether workers are forced to work

SB=Lists of social benefits provided to workers

D=Existence of sex discrimination during recruitment of workers

Table 12 Results of LCIA method by Ciroth and Franze (2011) for landfill

Stakeholder	Subcategory	PA	%CL	SW	FL	HS	SB	D	IA
Workers	Child labour	1	√	√	√	√	√	√	1
	Fair salary	4	√	√	√	√	√	√	4
	Forced labour	2	√	√	√	√	√	√	1
	Health and Safety	3	√	√	√	√	√	√	4
	Social benefit/social security	1	√	√	√	√	√	√	1
	Discrimination	1	√	√	√	√	√	√	1
	Amount	3							3
Society	Contribution to Economic Development	3	√	√	√	√	√	√	3
	Amount	3							3
Local community	Community engagement	6	√	√	√	√	√	√	6
	Amount	5							5
Total amount		**4.0**							**4.0**

only 8 % of workers in job at flake producing industry and 10 % working at incineration plant asserted not to be aware on this issue. Injury rate varied from 7.5 % (landfilling) to 10 % (flake producing industry) while no cases of injury were reported for the incineration workers.

As regards community engagement, flake producing industry was not involved in any community enhancement project, while the other two facilities did conduct projects and spent only 10 to 19 % of their CSR fund on the community. Consequently, the three facilities received the least marks for this particular sub-category.

When the scores were summed up for the three facilities, landfilling scored the least marks and highest score was obtained by the flake producing industry (scenario 4). Similar trend was observed when the disposal facilities results were converted to respective scenarios, as illustrated in Table 9. Table 9 also shows that the partial recycling scenario 4 predominate on incineration and landfilling. The scoring system thus allowed determining the hierarchy of social preference among the four disposal alternatives. The most preferred scenario is therefore scenario 4 (75 % flake production and 25 % landfilling).

6 Discussion

The current study presented a new LCIA method for:

- Converting qualitative inventory data into quantitative expressions
- Aggregating social inventory data to comparable units

The methodology developed uses a scoring system to assign marks to investigated indicators and sub-categories (which were selected from the list provided in the UNEP/SETAC Guidelines on S-LCA). Moreover, the model proposed is much simpler compared to other LCIA assessment methods; for example, the method proposed by Ciroth and Franze (2011) calls for expert judgement whilst the new method proposed here is based on logical scoring system and can be easily adapted to suit local conditions by adjusting its range. To illustrate its adaptation, the devised methodology was contextualized for Mauritius and used to assess the performance of the companies involved in the four different disposal scenarios of used PET bottles. The results obtained through this method were interpreted in the previous section and it was found out that least social impacts occur when 75 % of the used PET bottles are collected

Table 13 Results of LCIA method by Ciroth and Franze (2011) for incineration

Stakeholder	Subcategory	PA	%CL	SW	FL	HS	SB	D	IA
Workers	Child labour	1	√	√	√	√	√	√	1
	Fair salary	2	√	√	√	√	√	√	2
	Forced labour	1	√	√	√	√	√	√	1
	Health and Safety	2	√	√	√	√	√	√	1
	Social benefit/social security	1	√	√	√	√	√	√	1
	Discrimination	1	√	√	√	√	√	√	1
	Amount	1.34							1.17
Society	Contribution to Economic Development	3	√	√	√	√	√	√	3
	Amount	3							3
Local community	Community engagement	6	√	√	√	√	√	√	6
	Amount	5							5
Total amount		**3.11**							**3.06**

separately for flake production. In other words, human well-being is least impacted with the partial recycling scenarios.

To validate the new method, it was necessary to run the collected inventory data into another LCIA model and compare the results of both LCIA methods. To that effect, the LCIA method of Ciroth and Franze (2011) was selected. This LCIA method, as seen previously, uses colour grade and assigns factors to sub-categories and indicators. The main specific calculation rules as explained and used by Ciroth and Franze (2011) are:

- Each indicator within a sub-category is allocated a factor between 1 and 6 (Table 10).
- The factor assigned to each sub-category is the average sum of the factor allocated to its indicators.
- However, if any indicator within the sub-category or any sub-category is assigned a factor 6, then the average sum would be 5, similarly if a factor 5 is assigned then the average sum would be 4 and in case a factor 4 is assigned then the average sum becomes 3.
- The final 'score' is the average sum of all sub-categories considered.

Although the factor assigned to the sub-category and indicator is subjective (Ciroth and Franze 2011), these rules have been applied for the calculations of the three disposal scenarios (flake production, landfill and incineration). The results are shown in Tables 11, 12 and 13, respectively. In the tables the third and the last columns are assessment columns. While the first assessment column rates the company/sector performance (PA), the second assessment column covers the impact assessment (IA). The columns in between column 3 and the last column show the relationship between each sub-category and the considered impact categories. A tick represents a relationship.

The results obtained indicate that the lower the total amount, the better is the performance of the company involved in the disposal scenario. Thus it is clearly evident that flake production performs better than incineration which in turn performs better than landfilling. In brief, after comparison of the two LCIA methods, it is observed that both methods presented similar results implying that the new LCIA method is reliable. Moreover, in addition to the method proposed by Ciroth and Franze (2011), the new method has gone one step further by suggesting scores calculation for combined scenarios. Indeed the limitation has also been discussed and need to be further explored.

The E-LCA study conducted complements the S-LCA results and both studies favoured partial recycling scenario,

i.e. 75 % flake production and 25 % landfilling for the disposal of used PET bottles in Mauritius.

7 Conclusions

The case study investigated four disposal routes of used PET bottles with respect to two dimensions of sustainability (environment and social) within the context of Mauritius. The study showcased that recycling is not only beneficial from the environmental viewpoint but is equally socially valuable.

LCA results showed that the higher the recycling rate, the higher was the net environmental benefit. Consequently, scenario 4 (75 % flake production and 25 % landfilling) had the least environmental impact and was therefore the most environmentally efficient disposal route for used PET bottles. The highest environmental load occurred when all used PET bottles were sent to the landfill (scenario 1). The results and discussion enabled the establishment of a hierarchy from most preferred to the least preferred scenario as:

- Scenario 4 (75 % flake production and 25 % landfilling)
- Scenario 2 (75 % incineration and 25 % landfilling)
- Scenario 3 (40 % flake production and 60 % landfilling)
- Scenario 1 (100 % landfilling)

A new and simple methodology for aggregating inventory results was proposed in this case study and was used to determine the disposal route of used PET bottles with least social impacts. The results showed that scenario 4 was the most preferred scenario. The scoring system also set up a hierarchy from most preferred to the least preferred scenario as follows:

- Scenario 4 (75 % flake production and 25 % landfilling)
- Scenario 2 (75 % incineration and 25 % landfilling)
- Scenario 3 (40 % flake production and 60 % landfilling)
- Scenario 1 (100 % landfilling)

Results of both studies, E-LCA and S-LCA, indicated similar trend from the highest to the lowest preferred scenarios.

Thus the results of the Life Cycle Management tools (E-LCA and S-LCA) indicated that scenario 4 is the most preferred disposal route of used PET in Mauritius from both the environmental as well as social perspectives. The next step would be to investigate the third dimension of sustainability, i.e. economic pillar. The eventual goal will be to determine the life cycle sustainability assessment which will not only guide the Mauritian government to formulate appropriate policies but also would provide a sustainable path to tackle the problem of disposal of used PET bottles in Mauritius. Moreover, the present case study focussed on a particular component of solid wastes; however, similar procedures can be undertaken to manage the whole solid waste sector.

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